NOAA Technical Report NESDIS 9

The NESDIS-SEL Lear Aircraft Instruments and Data Recording System

Washington, D.C.
June 1984

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

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The NESDIS-SEL Lear Aircraft Instruments and Data Recording System

Gilbert F. Smith
Kenneth O. Hayes
John S. Knoll
Robert S. Koyanagi

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U. S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
National Oceanic and Atmospheric Administration
John V. Byrne, Administrator
National Environmental Satellite, Data, and Information Service
John H. McElroy, Assistant Administrator

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Abstract

Support of the NOAA-NESDIS Satellite Vicarious Calibration effort requires the use of aircraft mounted field instrumentation to conduct high altitude measurements of radiance from White Sands, New Mexico. Small laboratory spectrometers were adapted for aircraft environment and modified so that their visible wavelength dynamic range and their spectral and spatial characteristics were commensurate with specific satellite instruments.

Introduction

The need for current measurements of visible wavelength upwelling radiance from the Earth's surface from a high altitude aircraft stems from the question of performance stability of existing NOAA satellite instruments. If the aircraft and satellite instruments are identical in wavelength, dynamic range, and Earth surface footprint, then it becomes viable to compare the output data of these two instruments while viewing the same surface area of the Earth along the same vector at the same time. The aircraft instrument provides calibrated surface radiance which can be used to vicariously calibrate the concurrent satellite surface data. Recently, three aircraft instruments were flown for NOAA in the NASA Lewis Model 25 Lear jet* over White Sands, NM, in support of the NOAA Satellite Instrument Vicarious Calibration effort. Aircraft overflights of White Sands were also made at times not coincident with satellite overpasses. This data is used to generate an atlas of White Sands radiance.

*See Appendix A

1980-81 Instrument Description

The 1980-81 flight series was made primarily in support of vicarious calibration of the visible channels of the GOES VISSR instrument. During the last few flights of this series, some data was recorded in the view vector of the NOAA-AVHRR visible channels. Instrumentation consisted of two spectrometers mounted side by side in a cradle (figure 1) fitted into the Lear aircraft instrument bay. The NOAA Lear pod plate (figure 2) consisted of two pairs of quartz windows located so that the instruments could view either the nadir for the AVHRR, or 50° from the nadir for the VISSR. The aircraft instrumentation system is outlined in figure 3. Figure 4 shows the instruments installed over the Lear aircraft pod.

The primary instrument* is a 1/4 meter focal length Ebert spectrometer[1] (figure 5) with a silicon detector at the exit slit. The grating is ruled at 1200 groove/mm, and blazed at 500 nm. A cam-sine bar mechanism, driven by a 24 volt D.C. motor, is used to scan the grating every 6.0 seconds through the wavelength range of 480 to 960 nm. A photo diode system on the cam shaft provides timing pulses for data recording synchronization. A blocking filter is located in front of the detector to absorb all incident radiation below 475 nm. The slits are 3 mm diameter circles which produce a resolving power ($\lambda/\Delta\lambda$) of 100 and a 1 km^2 Earth surface footprint at 12.46 km altitude. The system signal to noise ratio was measured at 200:1. The output of the detector post-amplifier is fed to both the analog chart recorder and the digital data system.

Signal output variations of ±5% will occur when the scene polarization becomes in or out of phase with the instrument polarization, created by the

*Fabricated by Research Support Instruments, Inc.
Cockeysville, Maryland

grating grooves. To correct this, the scene is de-polarized by placing a quartz wedge in front of the entrance slit.

The second instrument* was a Filter Wedge Spectrometer[2] (FWS), which covers the wavelength range of 400-2400 nm. The FWS utilizes a three section filter wheel, synchronous motor driven and rotating at 10 RPM, with individual wavelength ranges of 400-700, 700-1300 and 1300-2400 nm, respectively, and a resolving power in range of 50 to 100.

The mechanical-optical system is illustrated in figure 6. A calcium fluoride lens serves as a system window and images the target (White Sands) on the entrance aperture. The rotating chopper and filter wheel are located in front of the entrance aperture. The entrance aperture is imaged by a second lens onto the Lead Sulfide detector, which is temperature controlled at 37°C. The beam chopper system consists of a synchronous motor driven, black anodized, two-bladed chopper wheel, rotating at 1200 RPM to produce a 400 Hz signal, and a photo diode system to provide electronic synchronous demodulation. A second photo diode system monitors the position of the filter wheel in time.

The chopped output signal of the detector is fed to the input of a lock-in amplifier, whose output is then applied to both analog chart recorder and the digital data system (figure 7).

Gain as a function of wavelength curves for the FWS and 1/4 meter spectrometer are shown in figures 8 and 9, respectively.

Calibration

The FWS wavelength calibration for the December 1980 flight is based solely on a technique established by F. Blaine of Goddard Space Flight

*Fabricated at
NASA Goddard Space Flight Center

Center using the emission lines of gaseous discharge tubes. The 1/4 meter spectrometer wavelength calibration for the December 1980 flight was accomplished with an incandescent lamp and a series of interference filters. For all flights after December 1980, the 1/4 meter spectrometer and Filter Wedge Spectrometer were calibrated for wavelength in the laboratory using the emission lines of gaseous discharge lamps.

Laboratory radiance calibrations were performed for all flight instruments using a 30-inch diameter integrating sphere source[3] internally coated with $BaSO_4$ white. The sphere source integrity is maintained by regular calibration with a source traceable to the National Bureau of Standards. Figure 10 shows the radiance versus wavelength characteristics of the sphere. In-flight aircraft instrument radiance calibration was accomplished by using two on-board flat diffuser plates, painted with $BaSO_4$ illuminated by a single 200 watt quartz halogen lamp powered by a constant current source. These diffuser plates were moved into and out of the individual spectrometer's field of view by an electric motor driven mechanism. This same electro-mechanical system provided for beam blocking to provide a zero reference. Regular viewing of these plates by the instruments during high altitude data runs produced information concerning the performance stability of the spectrometers in flight.

Additional radiance calibration for both instruments was performed using a portable target, external to the aircraft, placed directly under either of the two aircraft pod quartz windows. This external target consisted of a flat $BaSO_4$ diffuser plate illuminated by a 1000 watt quartz halogen lamp powered by a constant current source. Calibrations with this source were performed immediately before and after each daily flight, which monitored any changes in the transmission of the quartz window due to accumulated dirt films.

1980-81 Electronic and Data Recording System

The 1980-81 flight series used the 1/4 meter spectrometer and the Filter Wedge Spectrometer (FWS) as data sources. Figure 11 is a general data flow chart for the system. Data was converted to a digital format and stored on cassette tapes by an HP 9825 calculator/computer. A crystal-controlled clock timed the data acquisition. Information was recorded every 40 milliseconds during a flight leg or "run." Spectrometer analog output was digitized by a 12 bit A/D converter and stored with marker information that allowed calculation of the geographical position of the spectrometer surface footprint with respect to their scan periods. As a back-up, a 2-channel chart recorder was also flown which recorded the analog outputs of the spectrometers. The computer also ingested Inertial Navigation System (INS) data from the Lear jet and stored it at the beginning and end of each run. This included data such as latitude, longitude, track angle and distance to go. Aircraft attitude data, pitch, roll and yaw (PRY) was also recorded and stored on cassette tapes.

Operationally, the HP 9825 governed the entire data gathering sequence. Numerous options were available to the operator, but computer programs determined the order and format of the actual data storage once a particular mode of operation had been chosen. The data word format, data timing, and data tape format are shown in Figures 1, 2 and 3, respectively.

The following paragraphs pertain to the individual electronic units in more detail:

Analog-Digital Board

This board is controlled by the HP 9825 computer. The computer output delivers the address for the analog multiplexer (Ø for FWS, 1 for 1/4 meter). Then it sends a pulse to start the A/D conversion (12 digital offset binary bits). After the conversion is complete, the data is saved in a 16 bit latch to be read out later by the computer.

Inertial Navigation System Board

The aircraft Inertial Navigation System (INS) provides a continuous stream of real time information on the aircraft attitude (pitch, roll, yaw) and longitude-latitude location. The INS board circuitry provides for a regular interval sampling of the INS information. This information is placed on the scientific data tape in the header of each spectral scan. From this, the ground location of the spectral scan can be calculated.

Power Supply Board

The primary power source for this board is 115V 60Hz from the aircraft converter, which is then converted to + 5V DC and ± 15V DC for use in all other electronics boards. All instrument grounds are physically connected on this board to allow for a single point aircraft grounding scheme.

1982 Instrument Description

This flight series was made in support of the vicarious calibration of the visible channels of the VISSR and AVHRR satellite instruments of the GOES and NOAA spacecraft, respectively. The requirement for alignment of the aircraft instrument optical axis with the variable location of the polar orbiting satellites in the sky led to the design of a smaller instrument mounted in a cradle with variable elevation and azimuth positioning. The elevation and azimuth is motor driven. The instrument is mounted so that the optical beam passes through the center of the aircraft quartz window plate for all angles of elevation and azimuth. This requirement necessitated a redesign of the quartz window aircraft plate to the cone-shaped configuration shown in figure 12.

The instrument is an 1/8 meter focal length, f5, zero dispersion, double monochromator (figure 13). A silicon detector is placed at the exit slit. The grating used in the instrument is a 600 groove/mm, blazed at 500 nm. A cam-sine bar mechanism, driven by a stepper motor, is used to scan the grating every 5.08 seconds through the wavelength range of 480-1050 nm. A photo diode system on the cam shaft provides timing signals for data recording synchronization. A blocking filter is located in front of the detector to absorb all incident radiation below 475 nm. The double monochromator system employs three slits. The entrance and intermediate slits are each 1/4 mm wide and the exit slit is 1 mm in width. The resolving power of the instrument at 700 nm is 100. The wavelength range of the instrument includes more than one order. During the grating scan, it is necessary to insert and remove an additional blocking filter in front of the detector to absorb all radiation below 645 nm. The activating device for this filter is a two position, 28 volt D.C. rotating solenoid. When the grating scan reaches 780 nm, the grating drive stepper is halted, the order filter is inserted in the beam by the solenoid and the stepper restarted, all within .035 seconds. The order filter is removed from the beam during the cam retrace period of 0.71 seconds. There is a small loss of ground scan data during the .035 second halt of the grating drive. At an average aircraft ground speed of 0.2 km/second, there is a .007 km ground data loss during order filter insertion and a .142 km loss during scan retrace.

A foreoptics lens system adjusts the aircraft instrument field of view to a 1 km wide Earth surface swath, equal to that of the satellite instruments. A quartz wedge de-polarizer identical to the one used in the previous 1/4 meter instrument is mounted in the foreoptics lens assembly.

The relative radiance internal calibration source is a 2 inch diameter integrating sphere, painted white with $BaSO_4$ and illuminated by a 10 watt lamp powered by a voltage regulated source. This sphere is a part of the instrument foreoptics turret assembly, mounted on a rotating wheel and is driven by a 27V D.C. motor. This turret assembly rotates either the calibration sphere, the zero reference, or an open aperture, into the instrument beam. Additional calibration is performed using a portable source external to the aircraft, placed under the quartz window. This source is a 12 inch diameter, white painted integrating sphere illuminated by three 30 watt lamps powered by a constant current source. Calibrations with the external source are performed immediately before and after each daily flight, and serve to monitor any changes in the quartz window.

Figure 14 shows the 1/8 meter spectrometer cylinder, mounted in its elevation and azimuth rotation cradle, installed in the Lear pod directly over the cone pod plate (figure 12).

1982 Electronic and Data Recording System

The electronic instrumentation system mounted in the Lear jet for this flight series was essentially the same as the 1980-81 configuration (figure 3) except that the FWS electronic units were not included. New software was generated to control the operation of the 1/8 meter spectrometer, its elevation and azimuth position, the rotation of the foreoptics turret assembly and the solenoid for order filter insertion. A new control panel was also fabricated.

The data recording system was the same as that used in the 1980-81 flight series and has been described.

1983 Instrument Description

The May 1983 flight series was in support of the vicarious calibration of visible channels 1 and 2 of the Coastal Zone Color Scanner (CZCS) on board the Nimbus-7 satellite. Flight were made over ocean water off the eastern U.S. coast. The instrument and aircraft interface were the same as that used for the 1982 White Sands mission with the exception of the wavelength range. A new wavelength cam was installed in the 1/8 meter spectrometer to cover the range from 400-800 nm. The second order filter insertion feature was disconnected, producing a continuous grating scan of 5.79 seconds duration, which includes the 0.71 second retrace. No external aircraft calibration source was used for this flight series. The spectrometer was installed in the aircraft in the same manner as the previous flights of 1982 (figure 14).

1983 Electronic and Data Recording System

The instrumentation, electronic and data recording system of this flight series was identical to that of the 1982 flight series (figure 3).

References

1. W. G. Fastie, J. Quant. Spectrosc. Radiat. Transfer, Vol. 3, pp 507-518 (1963).

2. W. A. Hovis, Kley, and Strange, Applied Optics, Vol. 6, No. 6, p. 1057 (1967).

3. W. A. Hovis, J. S. Knoll, Applied Optics, Vol. 22, p. 4004, (Dec. 1983).

Acknowledgments

The authors wish to thank our colleagues in the NESDIS SEL Experimental Applications Branch, Messrs. Robert Levin, Peter Abel, Lee Johnson, and Frank Mignardi for their many contributions to the instrument electronic design, assembly, testing and calibration; and in the Technical Services Group, Messrs. Calvin Jones, Edward King and John Bray for their contributions to the instrument mechanical design, assembly and aircraft integration.

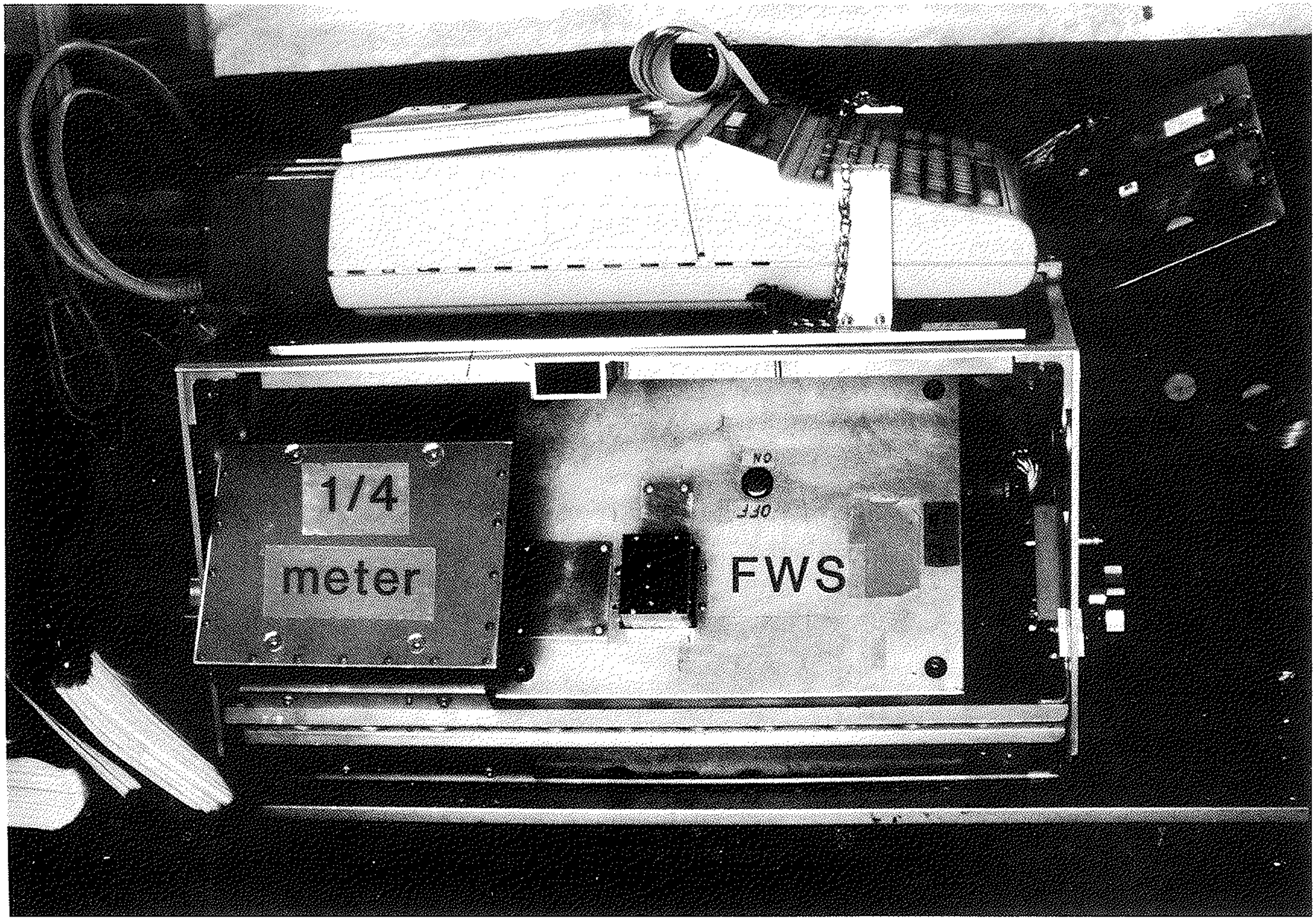


Figure 1.--Photo of FWS and 1/4 Meter Spectrometer Mounted in the Lear Cradle.

Lear Instrument Pod Plate
1980-81

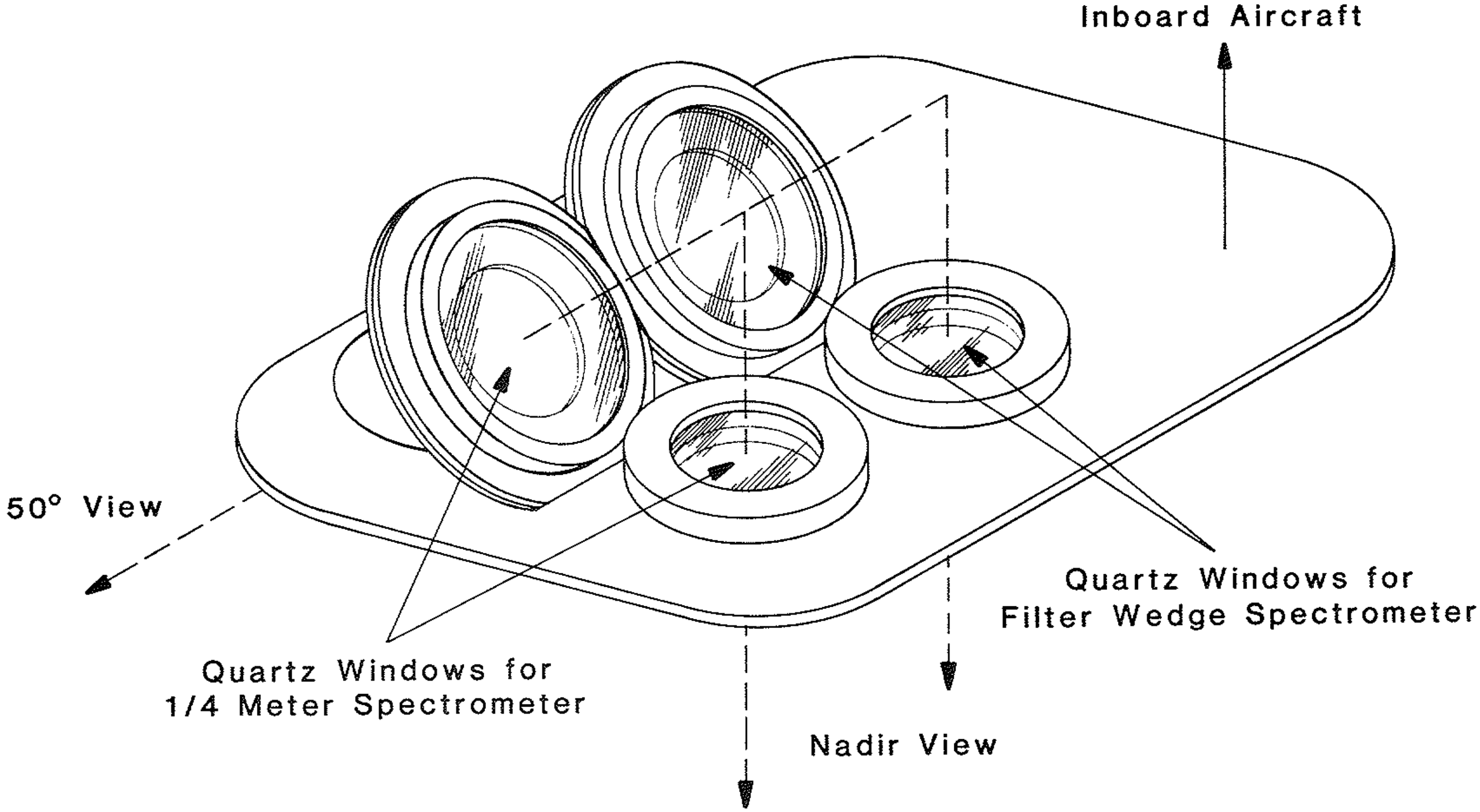


Figure 2.--1980-81 Lear Instrument Pod Plate.

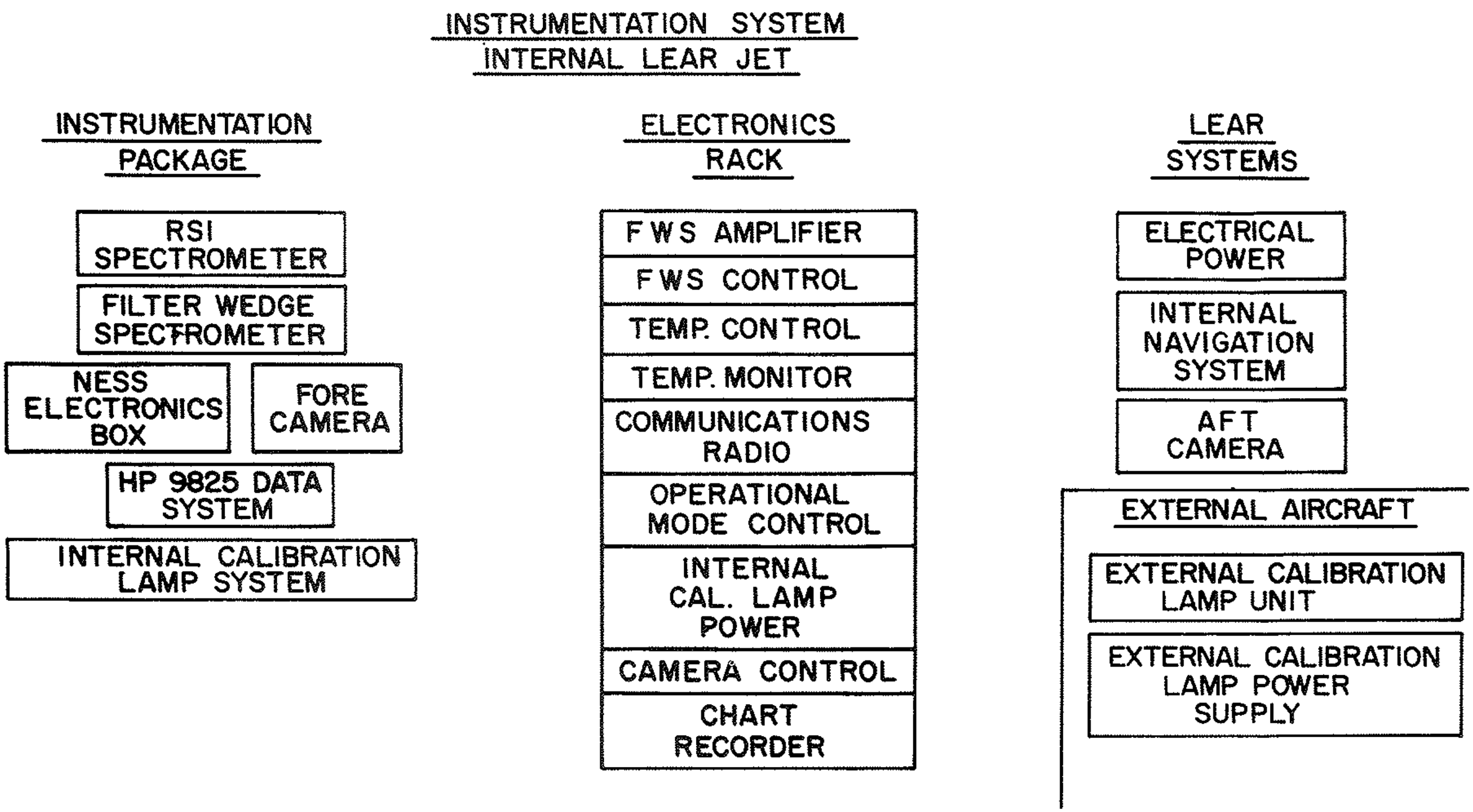


Figure 3.--Aircraft Instrumentation System.

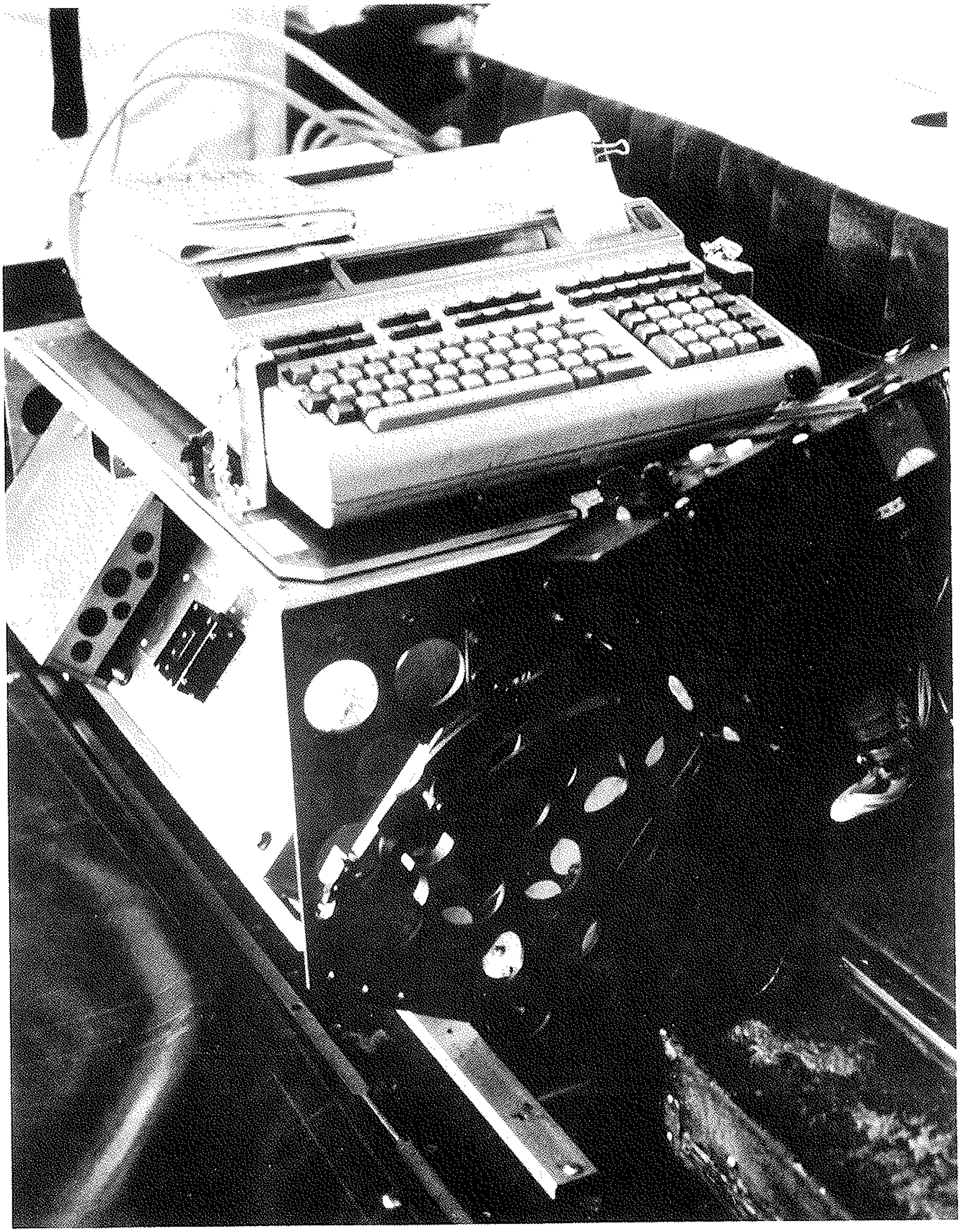


Figure 4.--Photo of FWS and 1/4 Meter Spectrometer in the Lear.

1/4 Meter Ebert Spectrometer

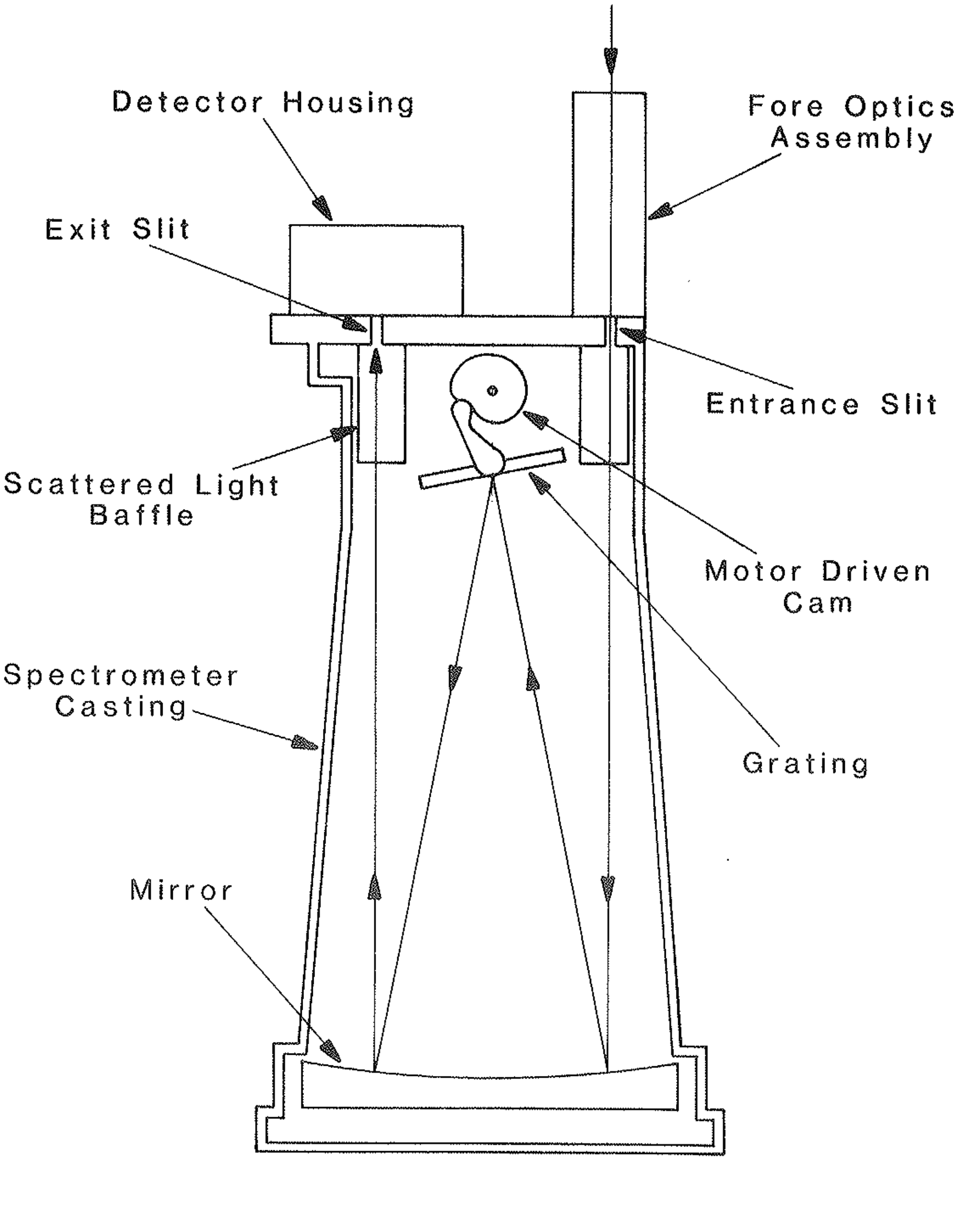


Figure 5.--1/4 Meter Ebert Spectrometer.

Filter Wedge Spectrometer Optical System

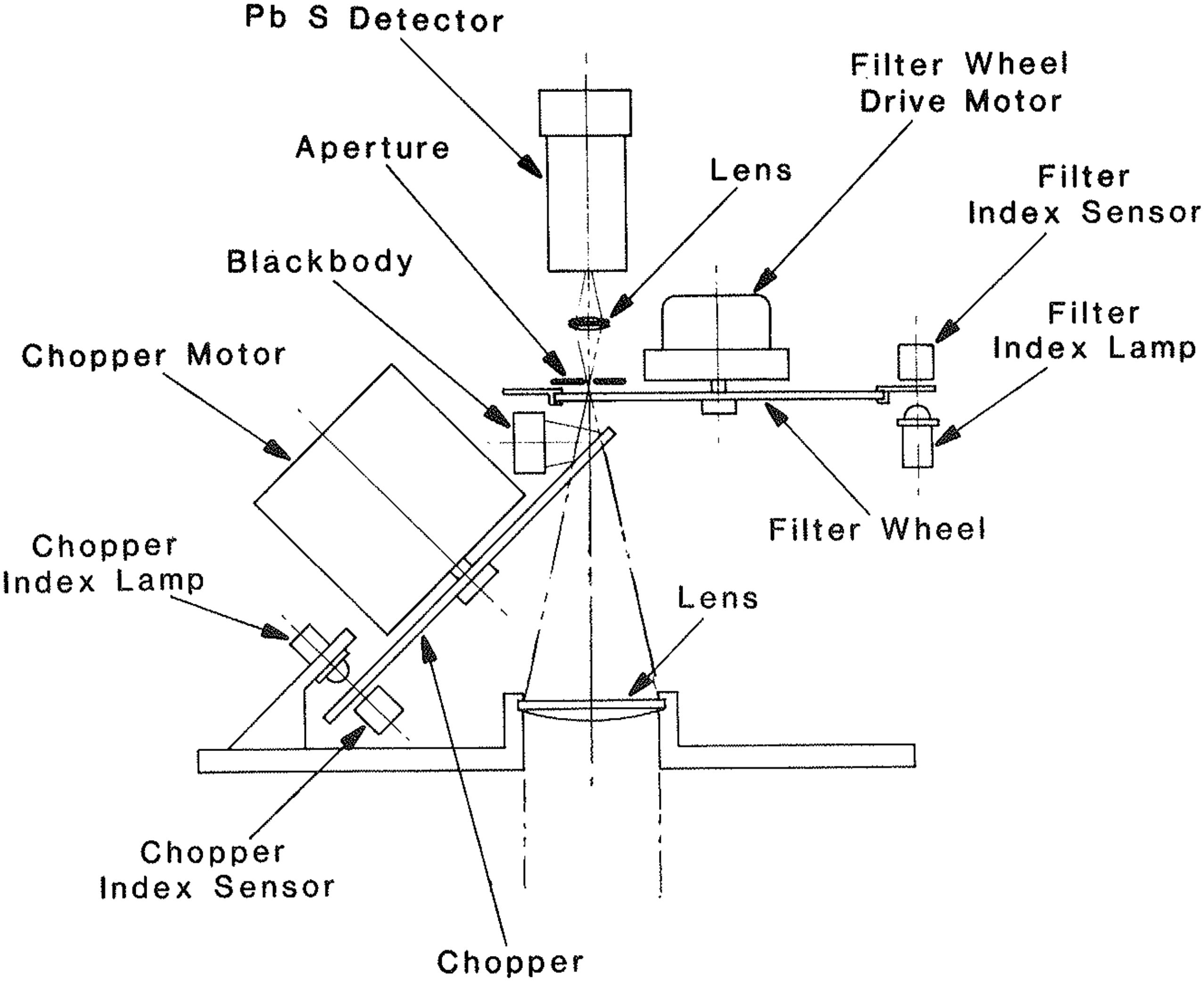


Figure 6.--FWS Optical System.

Digital Data System

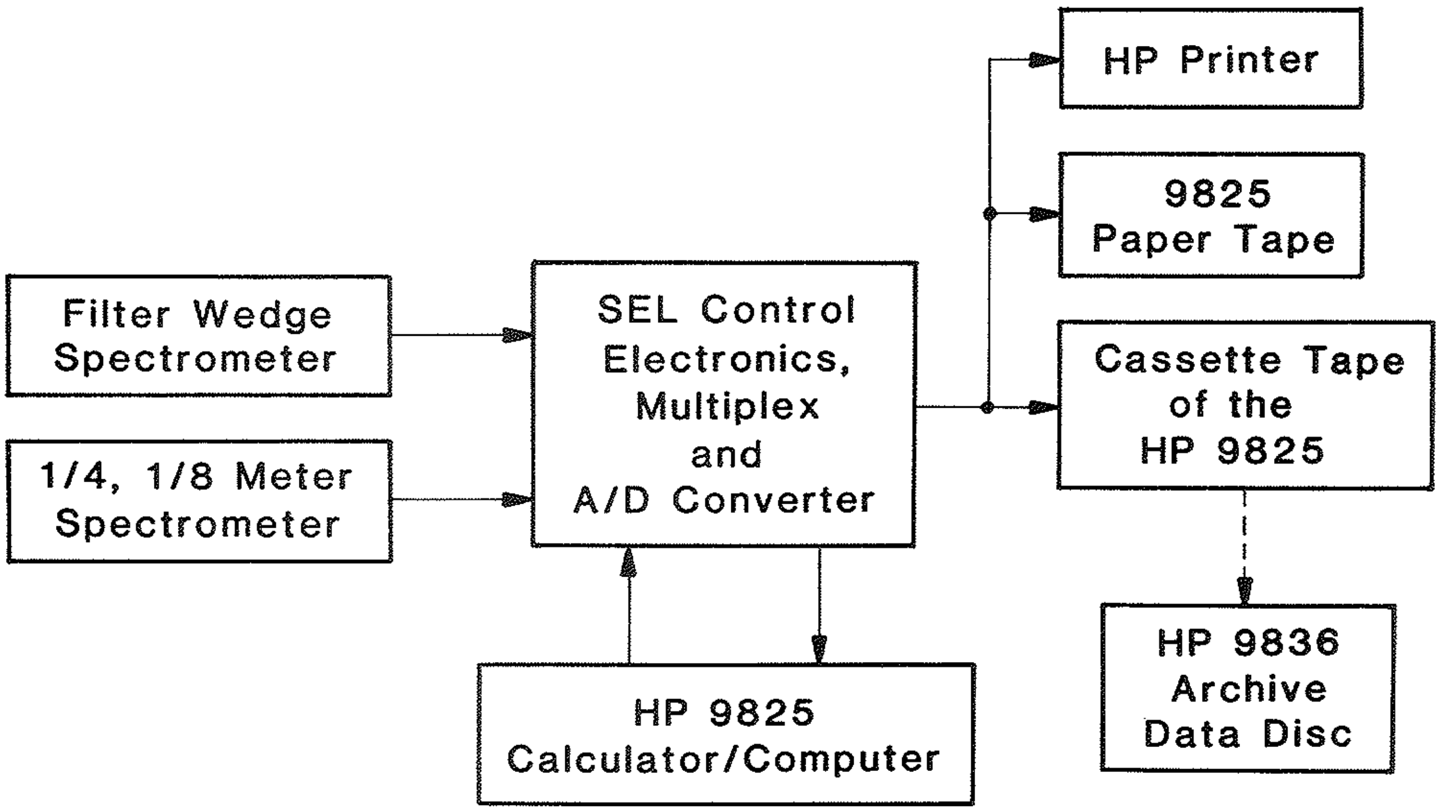


Figure 7.--Digital Data System.

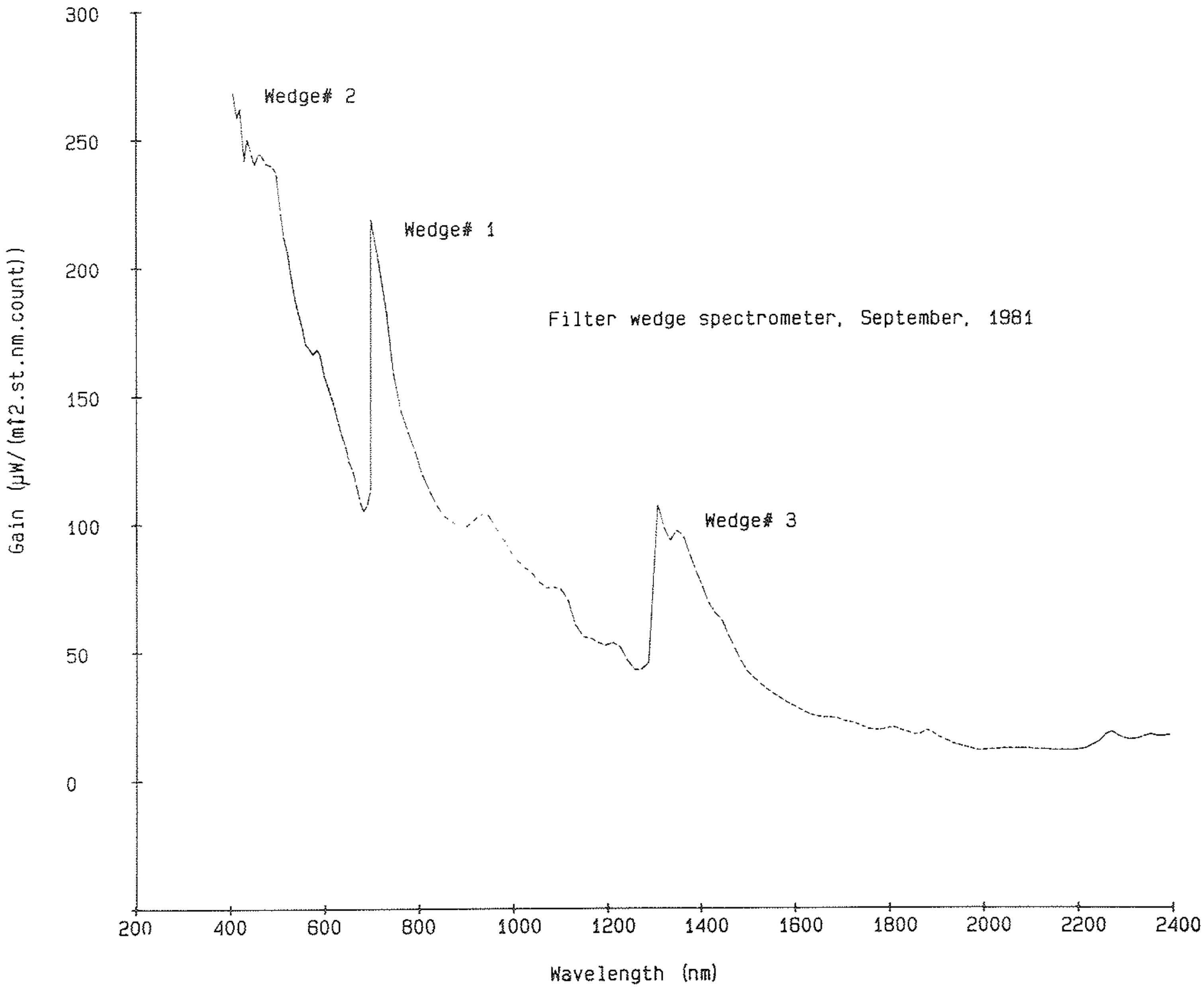


Figure 8.--FWS Gain Function Curve.

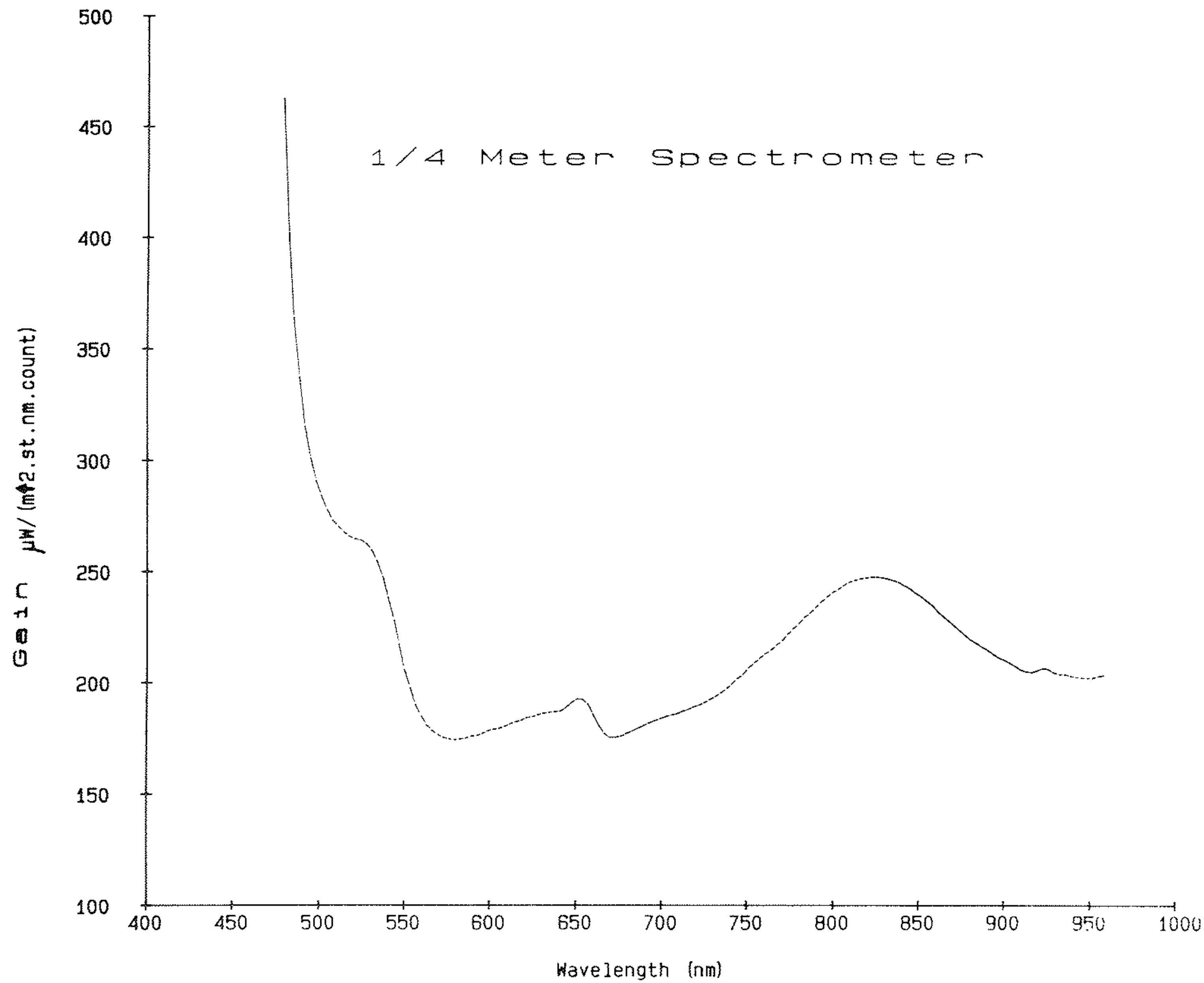


Figure 9.--1/4 Meter Spectrometer Gain Function Curve.

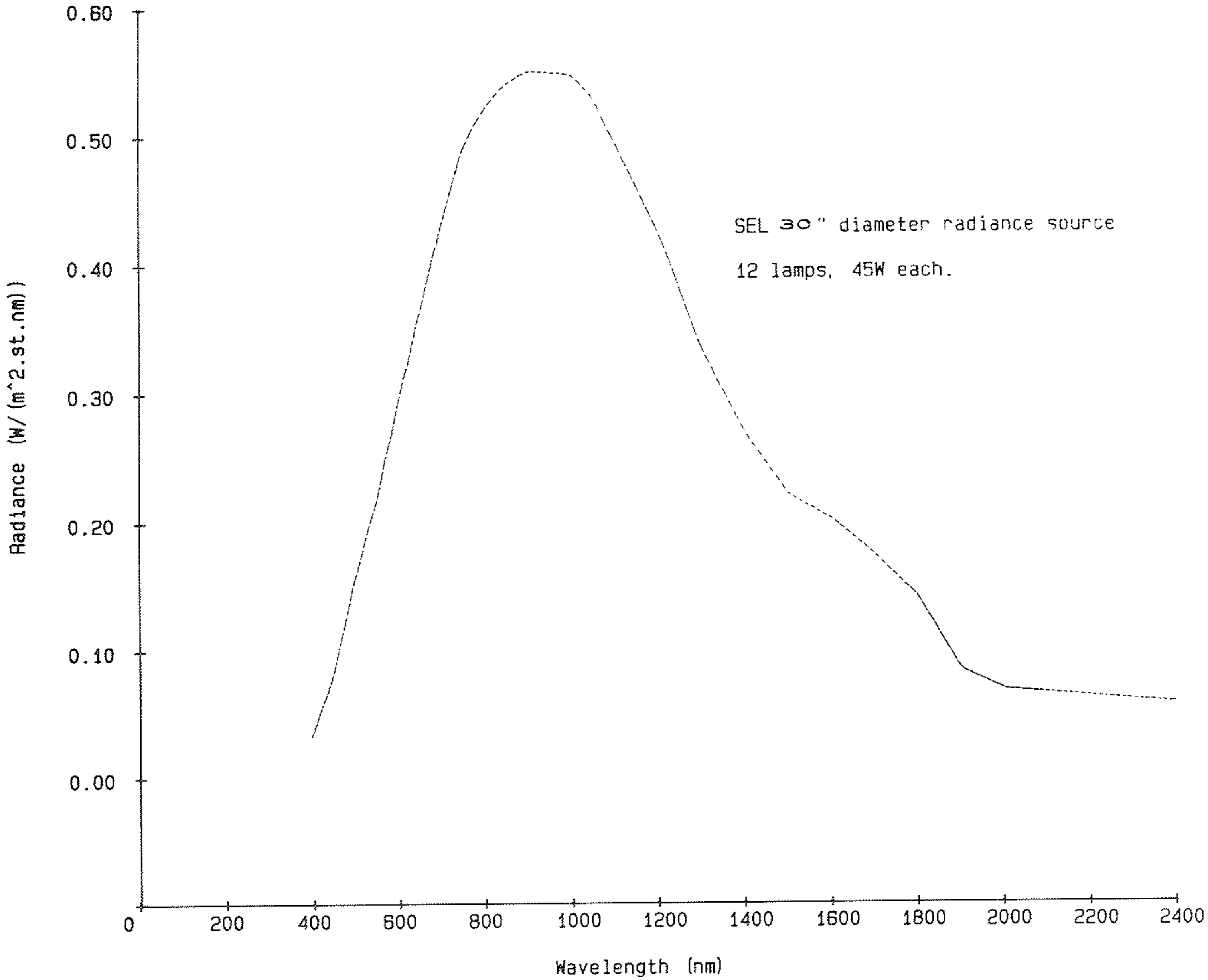


Figure 10.--Wavelength Characteristics of the Sphere.

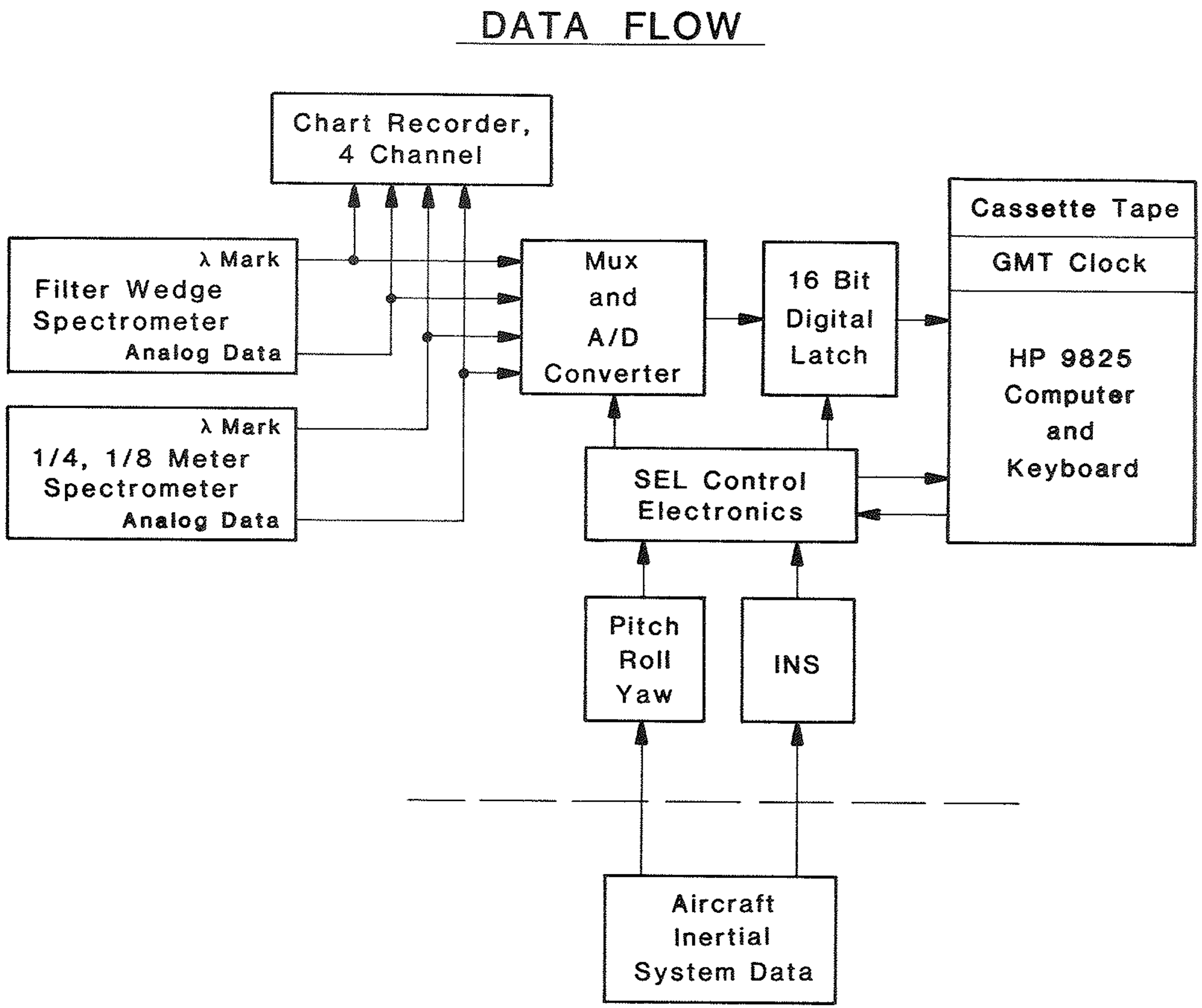


Figure 11.--Data Flow Chart.

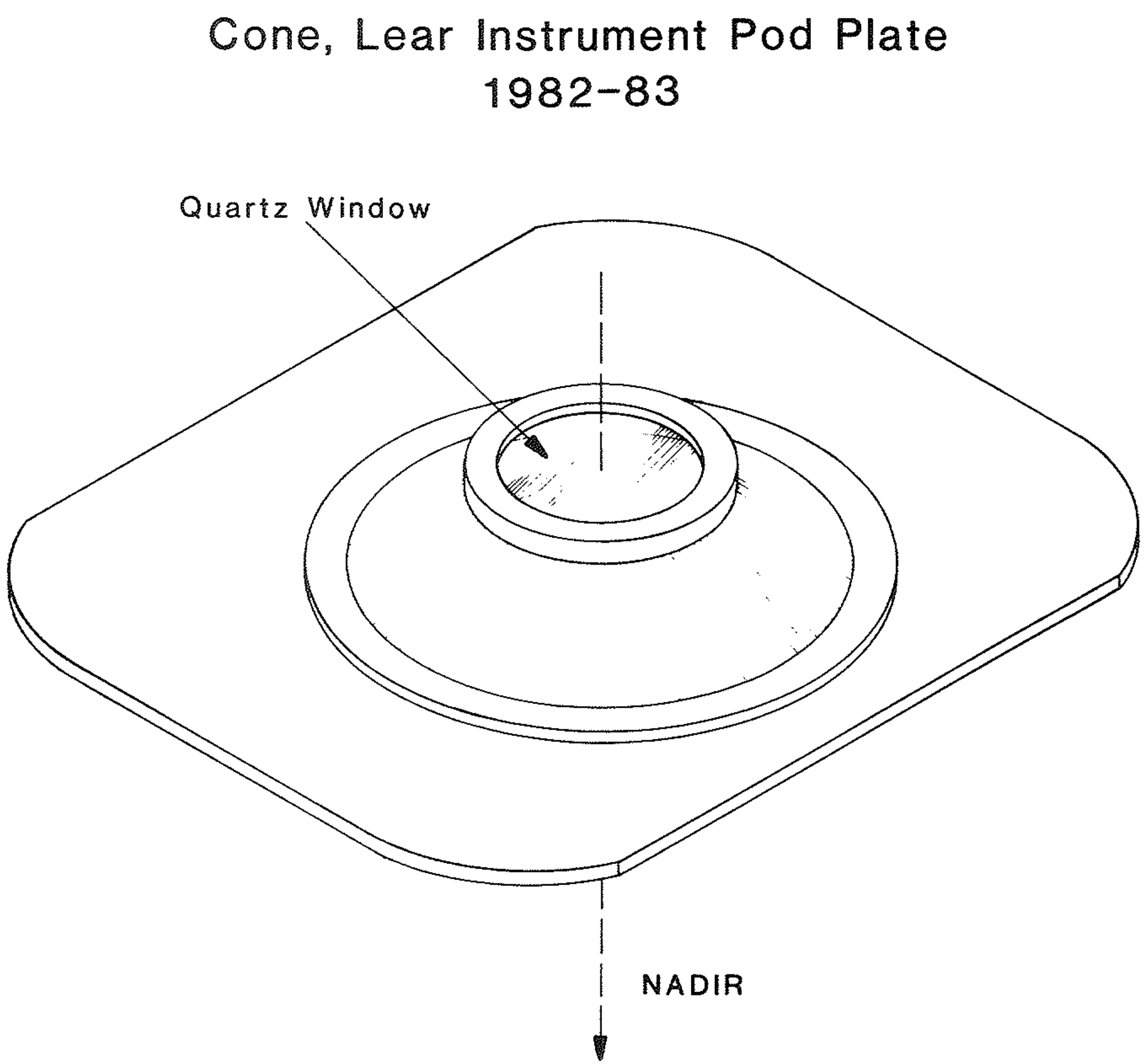


Figure 12.--Cone, Lear Instrument Pod Plate, 1982-83.

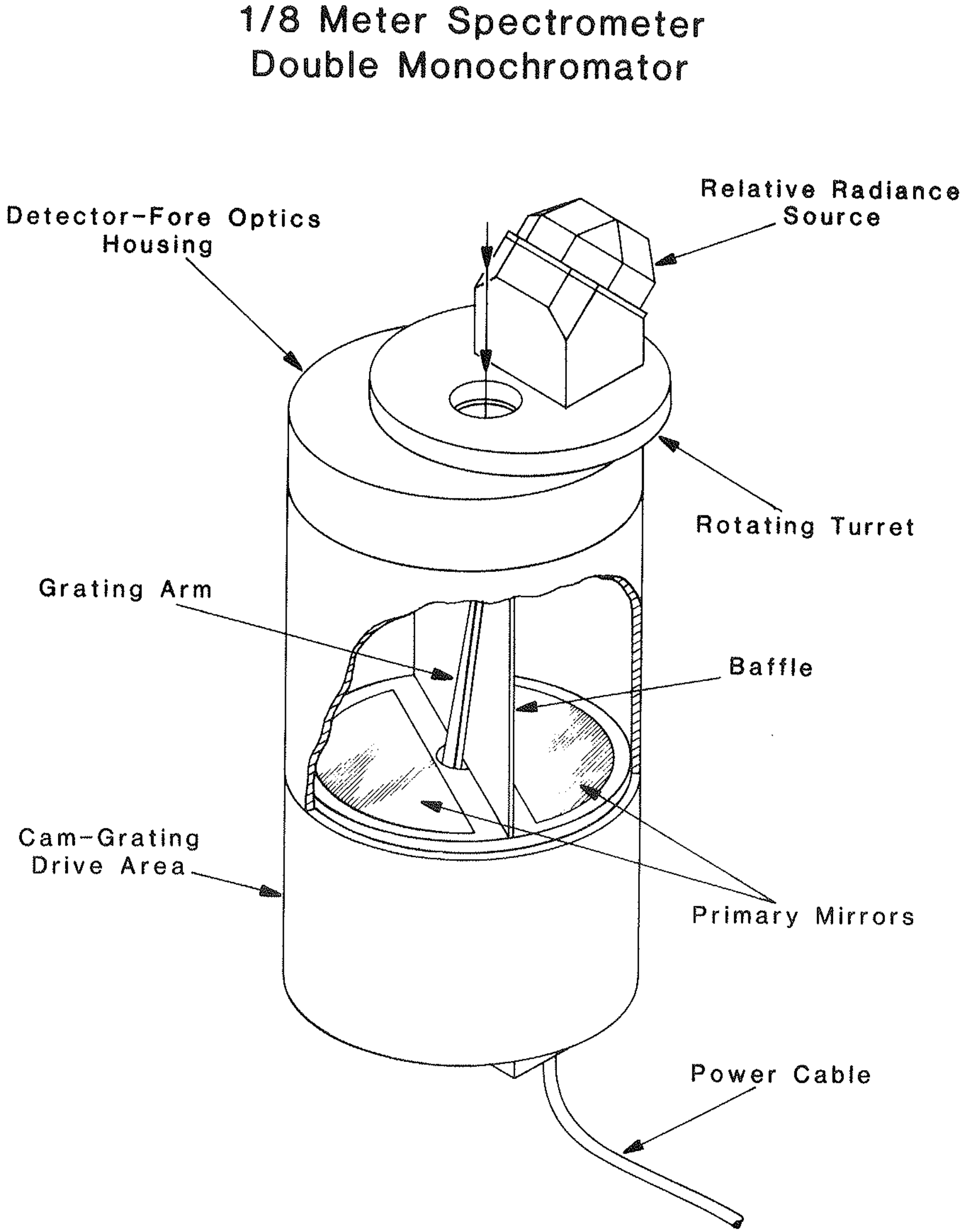


Figure 13.--1/8 Meter Spectrometer, Double Monochromator.

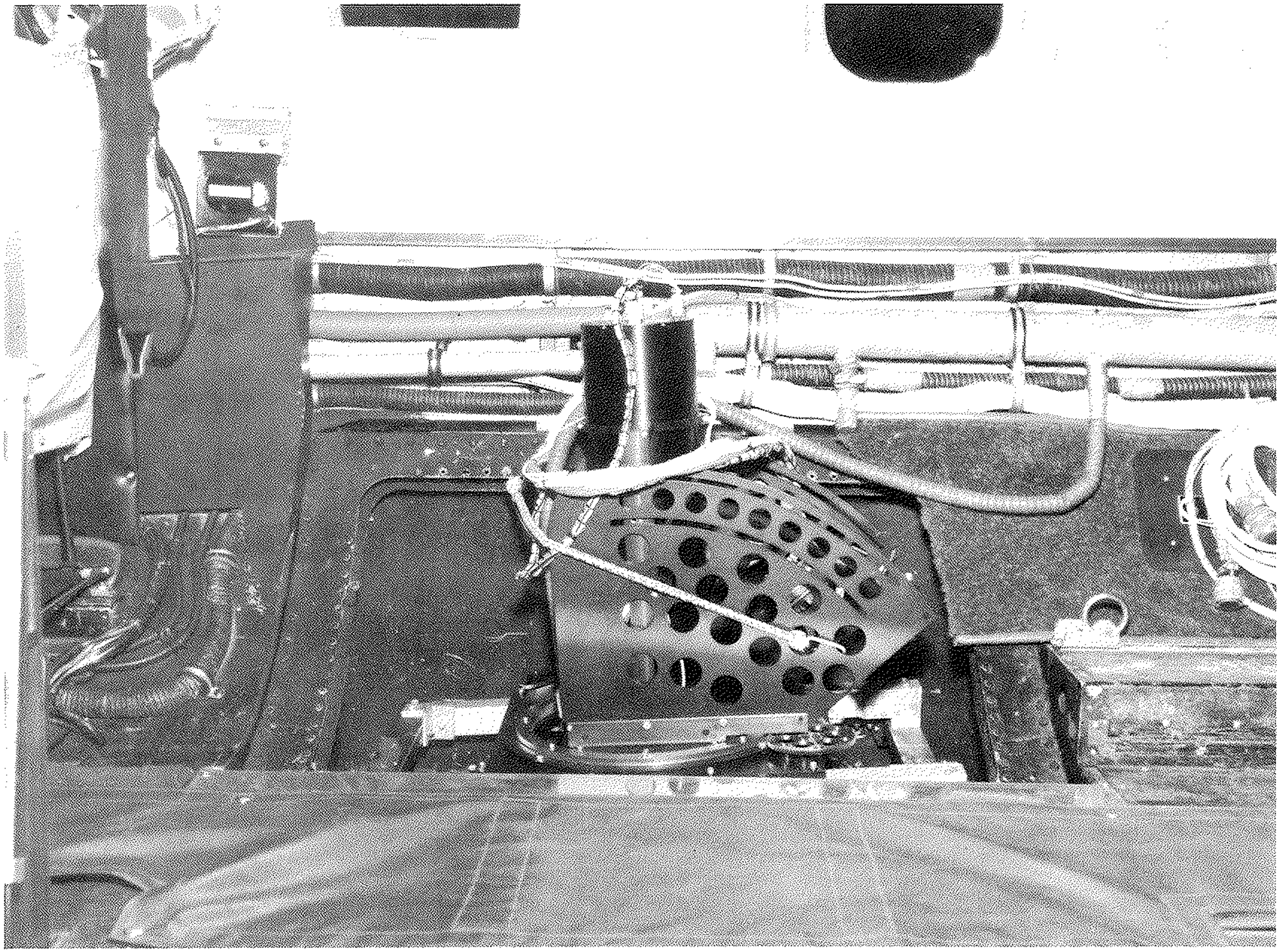


Figure 14.--Photo of 1/8 Meter Spectrometer in the Lear.

Table 1.--Data Word Format

16 Bit Data Word Format
1980-81

R	F	X	M	12 Bit A/D											
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Where:

R = a 1 if 1/4 meter tick mark present

F = a 1 if FWS tick mark present

X = not used

M = A/D output address (1 = 1/4 meter, 0 = FWS)

16 Bit Data Word Format
1982-83

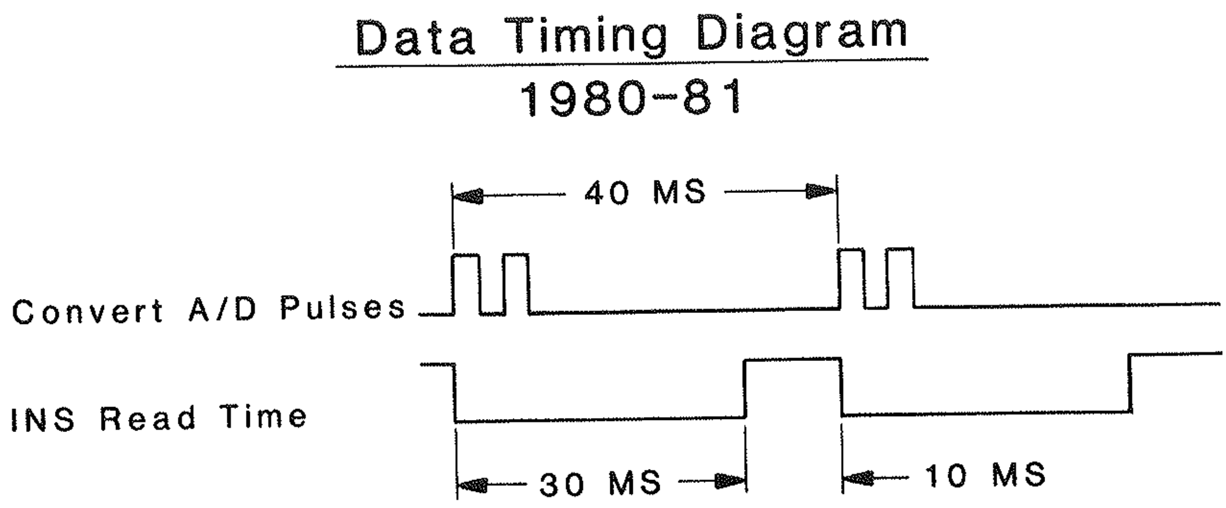
R	M	M	M	12 Bit A/D											
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Where:

R = a 1 if 1/8 meter tick mark present

M = A/D output address (1 = 1/8 meter)

Table 2.--Data Timing Format



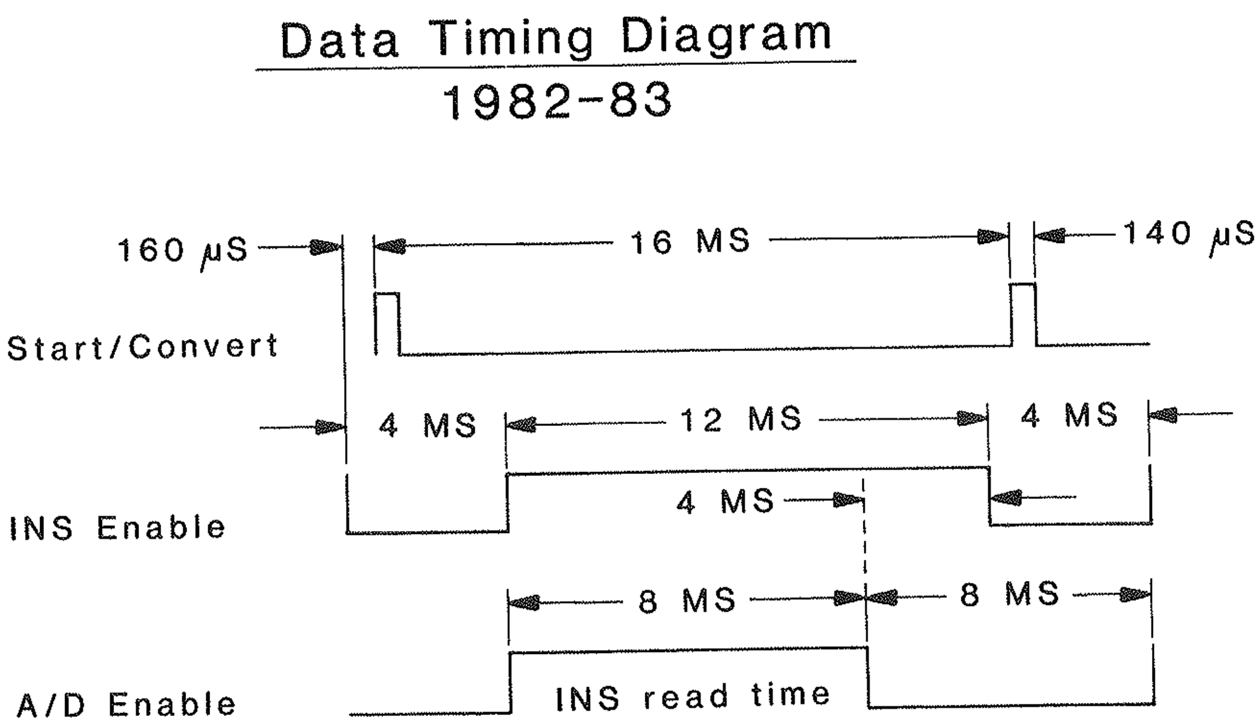


Table 3.--Tape Format
(Track Ø and Track 1 Identical)

File		Size (Bytes)
Ø	PGM[1]	15,000
1	KEYS[2]	300
2	IDENT	24
3	CAL 1	4,108
4	CAL 2	4,108
5	CAL 3	4,108
6	CAL 4	4,108
7	HDR 1	686
8	RSI 1	12,008
9	FWS 1	12,008
10	PRY 1	18,008
11	CAL 5	4,108
12	CAL 6	4,108
13	HDR 2	686
14	RSI 2	12,008
15	FWS 2	12,008
16	PRY 2	18,008
17	CAL 7	4,108
18	CAL 8	4,108
		133,632 BYTES PER TRACK

[1] File Ø contains the program

[2] File 1 contains subroutines

APPENDIX A

NASA LEAR JET
AIRBORNE RESEARCH LABORATORY

1.0 Introduction

The National Aeronautics and Space Administration operates a Model 25 Lear Jet for approved research projects. The Model 25 Lear Jet is an eight passenger aircraft with a nominal operating range of 1200 nautical miles. The aircraft is certified to an altitude of 45,000 feet; however, under certain circumstances higher altitudes can be obtained.

The aircraft is based at the Lewis Research Center (LeRC), Cleveland, Ohio, which is located adjacent to the Cleveland Hopkins Airport. It is preferable to operate the Lear out of the Lewis facility. However, if the research requirements so dictate, the aircraft can be deployed to airports with a minimum runway length of 6,000 feet. Remote operations must be approved by the Lewis Aircraft Operations Office.

2.0 Basic Aircraft Description

The Lear Jet Model 25 (figure 1) is an eight-passenger high-performance aircraft powered by two General Electric CJ-610-6 jet engines delivering a maximum thrust of 2950 pounds each. The engines are equipped with thrust reversers and the aircraft has provisions for a drag chute. The aircraft is of all metal construction and is characterized by its T-shaped empennage and permanently mounted wing-tip fuel tanks.

The Lear Jet instrument door pod (figure 2), a temporary device, was installed on the port side for the NOAA White Sands flights of 1980. A permanent instrument pod (figure 3) was installed on the starboard side by NASA in 1981 and is currently still in use.

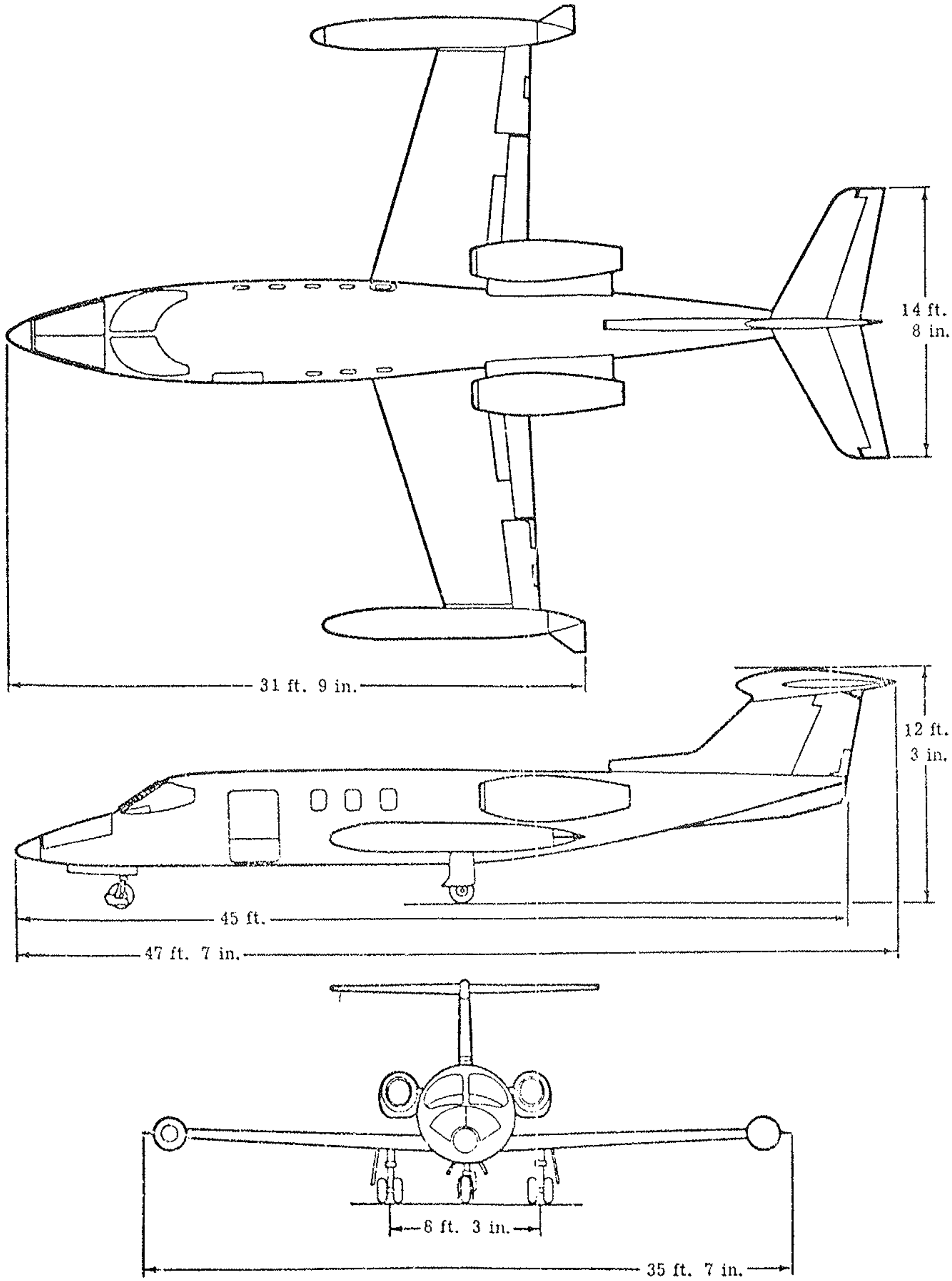


Figure 1A.--Lear Jet Illustration.

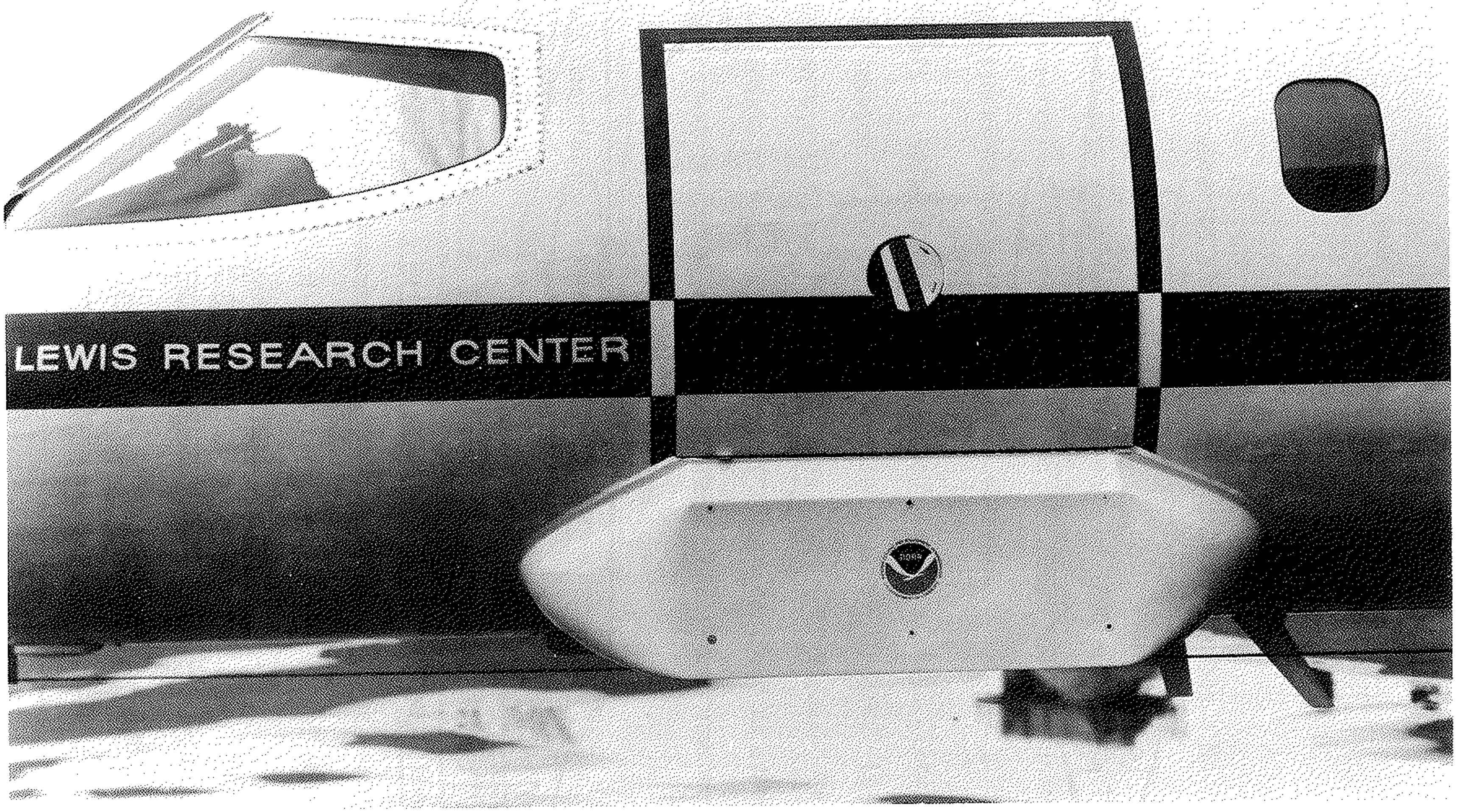


Figure 2A.--Lear Temporary Door Pod.

Figure 3A.--Lear Permanent Pod.

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established as part of the Department of Commerce on October 3, 1970. The mission responsibilities of NOAA are to assess the socioeconomic impact of natural and technological changes in the environment and to monitor and predict the state of the solid Earth, the oceans and their living resources, the atmosphere, and the space environment of the Earth.

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